

Fabrication and Characterization of Triple-junction Amorphous Silicon Based Solar Cell with Nanocrystalline Silicon Bottom Cell

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ABSTRACT

Highlights of recent research activities and results on the project “The Fabrication and Characterization of High-efficiency Triple-junction a-Si Based Solar Cells” at the University of Toledo (UT) under the NREL TFPP Program are briefly reviewed in this paper. Using VHF PECVD, new growth regimes have been established at UT for preparation of high quality a-Si, a-SiGe and nc-Si i-layers at rates of 2-15 Å/s. Initial efficiencies of 7.2%, for VHF nc-Si n-i-p single-junction solar cells, 9.6% for a-Si/nc-Si tandem cells, and 11.0% for a-Si/a-SiGe/nc-Si triple cells have all been achieved. The progress of our research on high-rate nc-Si deposition using high pressure (8 Torr) PECVD is also reported.

1. Objectives

General project objectives of “The Fabrication and Characterization of High-efficiency Triple-junction a-Si Based Solar Cells” are to establish a transferable knowledge/technology base. Specific objectives are to: a) improve understanding of limits to stabilized device efficiency and process stability on a quantitative basis; b) develop methodologies for processing a-SiGe and nc-Si subcells with higher deposition rates while maintaining or increasing stabilized cell performance.

2. Technical Approach

The effort in this project includes:

- fabricating single junction cells as well as complete tandem and triple junction cells;
- testing new or modified schemes for fabrication of narrow gap materials and cells at higher rates;
- improving device efficiencies through a combination of beneficial processing schemes;
- characterizing film growth relevant to real solar cell structures, including an assessment of the value of existing capabilities for on-line diagnostics.

Highlights of activities during this period include:

- development of high quality a-Si, a-SiGe and nc-Si i-layers using VHF PECVD at rates of 2-15 Å/s;
- fabrication and optimization of a-Si, a-SiGe and nc-Si n-i-p single, a-Si/nc-Si tandem and a-Si/a-SiGe/nc-Si triple-junction solar cells; and
- study of high-rate nc-Si using high-pressure, high power PECVD with variations in electrode spacing and externally applied voltage bias on the substrate.

3. Results and Accomplishments

3.1 a-Si, a-SiGe and nc-Si single-junction solar cells

Based on our previous research on a-Si based solar cells^[1] and using Si:H phase diagrams^[2], high quality a-Si, a-SiGe and nc-Si i-layers have been developed using VHF PECVD in new deposition regimes at rates of 2-15 Å/s. Their corresponding device performances have been evaluated using the n-i-p single-junction structure on SS/Ag/ZnO substrates. The n-layer and p-layer depositions have also been optimized. Table 1 lists representative IV data for a-Si, a-SiGe and nc-Si single-junction cells. With a deposition rate near 3 Å/s, the a-Si cell has an initial efficiency η of 9.3% with an i-layer thickness d of 160 nm, the a-SiGe cell has η =10.4% with d =180 nm, and nc-Si cells have η =6.6% and η =7.2% at i-layer deposition rates r_{dep} of 10 Å/s and 2.5 Å/s, respectively. IV and QE curves of the VHF nc-Si cell with r_{dep} ≈2.5 Å/s and d =1350 nm are also shown in Figs. 1 and 2.

3.2 a-Si:H/nc-Si:H tandem-junction solar cells

A representative initial efficiency of η =9.6% (V_{oc} =1.40 V, J_{sc} =10.4 mA/cm² and FF=0.66) for an a-Si/nc-Si tandem solar cell was obtained. a-Si and nc-Si i-

Table 1. IV data of a-Si, a-SiGe and nc-Si cells.

Cell	i-layer r_{dep} (Å/s)	i-layer t (min)	V_{oc} (V)	J_{sc} (mA/cm ²)	FF	η (%)
a-Si	3	9	0.969	13.4	0.72	9.3
a-SiGe	3	10	0.813	19.5	0.66	10.4
nc-Si	10	25	0.453	21.3	0.68	6.6
nc-Si	2.5	90	0.479	23.1	0.65	7.2

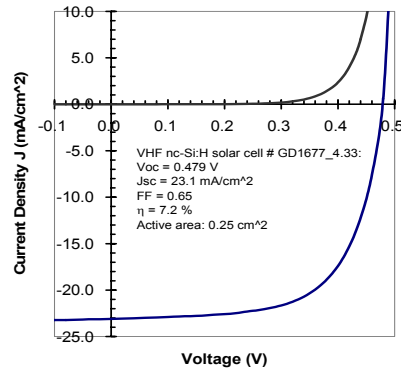


Fig. 1. IV curve of a UT fabricated VHF nc-Si:H n-i-p single-junction solar cell at a deposition rate of 2.5 Å/s.

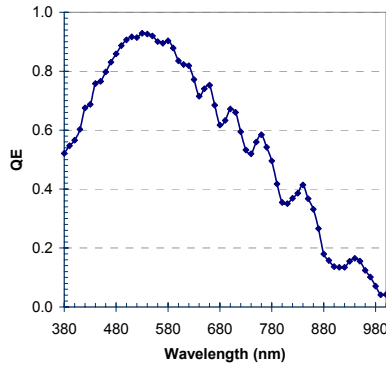


Fig. 2. QE curve of a VHF nc-Si:H solar cell whose IV data are shown in Fig 1.

Table 2. IV data of a-Si/nc-Si tandem-junction cells.

Cell Nr.	V_{oc} (V)	J_{sc} (mA/cm ²)	FF	η (%)
GD1645 initial	1.400	10.4	0.66	9.67
GD1645 100hrs light soaking	1.350	10.7	0.66	9.48

layers of the tandems were made using VHF with $r_{dep}=3 \text{ \AA/s}$ and $r_{dep}=10 \text{ \AA/s}$, respectively. IV data for 100 hr light soaking on the a-Si/nc-Si tandems shows only a small percentage (1.5%) degradation (see Table 2).

3.3 a-Si:H/a-SiGe:H/nc-Si:H triple-junction solar cells

As displayed in Table 3, an initial efficiency of $\eta=10.3\%$ has been obtained for the triple-junction cell (tri-cell C1), which is composed of a RF a-Si top-cell, a RF a-SiGe mid-cell and a VHF nc-Si bot-cell. $\eta=11.0\%$ has been obtained for a VHF a-Si:H/a-SiGe:H/nc-Si:H triple-junction cell (tri-cell C2). The deposition time of tri-cell C2 has been greatly reduced, while its efficiency has been kept within the same range as C1. The QE of the tri-cell C2 is also shown in Fig. 3.

3.4 High-rate nc-Si using high pressure/power PECVD

Improvement of nc-Si cells within the high-rate regime has been achieved by using a DC bias voltage. Although the rate is independent of bias at $\sim 9.5 \text{ \AA/s}$, a cell made at +20 V provides a higher initial efficiency

Table 3. IV data of a-Si/a-SiGe/nc-Si cells..

tri-cell	structure	i-layer t (min)	V_{oc} (V)	J_{sc} (mA/cm ²)	FF	η (%)
C1	RF a-Si top-cell	85	2.132	7.23	0.67	10.3
	RF a-SiGe mid	60				
	VHF nc-Si bot	25				
C2	VHF a-Si top-cell	9	2.098	7.61	0.69	11.0
	VHF a-SiGe mid	14				
	VHF nc-Si bot	28				

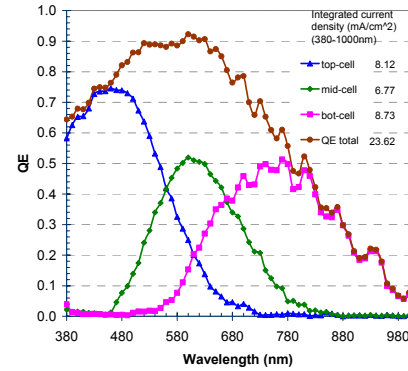


Fig. 3. QE spectra of VHF a-Si:H/a-SiGe:H/nc-Si:H triple-junction solar cell.

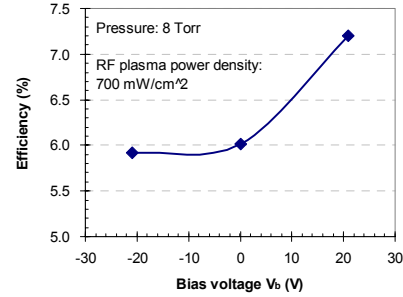


Fig. 4. Efficiency versus bias voltage.

of 7.2% ($V_{oc}=0.491\text{V}$, $J_{sc}=22.2 \text{ mA/cm}^2$ and $FF=0.66$) than one made at zero bias (grounded substrate), whereas a cell made at -20 V does not show any improvement (see Fig. 4). J_{sc} , FF and QE behaviors for each bias suggest improvement of film quality by applying the positive bias. Moreover, negative and positive DC biases alter the crystal volume fraction to higher and lower values, respectively.

4. Conclusions

We have successfully fulfilled our first period research tasks in the fabrication and characterization of a-Si, a-SiGe and nc-Si single-junction, a-Si/nc-Si tandem-junction and a-Si/a-SiGe/nc-Si triple-junction solar cells using VHF PECVD as well as high-pressure, high power PECVD. In the next period, we will incorporate real-time spectroscopic ellipsometry (RTSE) into the triple-junction cell fabrication system to determine phase diagrams for a-Si, a-SiGe and nc-Si i-layers. With a better understanding of the processes, improvements in efficiencies are expected.

ACKNOWLEDGEMENTS

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